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NOTES ON A THEORY FOR FOREST FIRE PROTECTION EXPENDITURES

By

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California Forest and Range Experiment Station

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Introduction

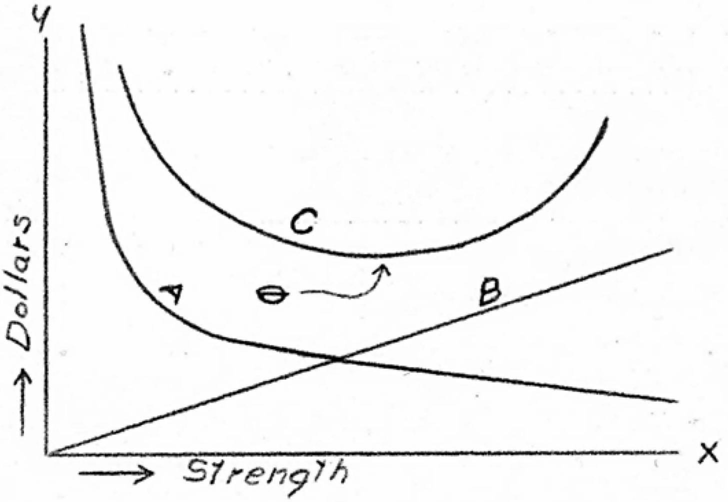
The minimum cost theory has largely failed as a guide to fire protection needs. That, in the opinion of the writer, is due to lack of clear understanding and enunciation of the theory.

Indexes are currently and constantly needed for fire control expenditures. Controversies exist as to allowable burned acreage and justifiable costs of protection. Jealousy springs up on the distribution of funds between units. Complicated formulas and techniques are suggested but not accepted as solutions. These needs would be filled and the controversies would disappear if the fundamental economic laws governing these expenditures were discovered and clearly enunciated. A preliminary study for these purposes is presented here.

Hypotheses

The study is based upon the following hypotheses: that increase in strength of force will be accompanied, in general, by a reduction in acreage burned; that such reduction must take the form of a curve of diminishing returns; and, that knowing the damage per acre of land burned, strength of protection force, it is possible to arrive through economic analysis at the precise expenditure justified in a protection organization.

These hypotheses may be best illustrated by reference to the diagram. If strength in fire control organization be plotted on the



x axis and dollars on the y, damage by fires will decrease in general in accordance with the general form of curve "A". Suppression costs will likewise decrease as in "A" and inasmuch as both costs will react similarly, "A" may be considered a combination of both damage and suppression costs. Preparedness costs will, on the other hand, take the form of line "B". If all costs are added, a curve of the form shown in "C" will result with a point of inflection at θ. This is the point of most effective protection. θ also defines the amount of burned area which will result from efficient protection. If these points are established, the controversies disappear, as practically any question in fire control economics can be settled from these relationships.

Description of Data

To test these hypotheses protection statistics of the 12 national forests of the California pine region were utilized. Former studies[1/] have fully described the fire protection problem on these 15 million acres of public forest land. The period chosen for study was 1921-1937. Earlier statistics were not used because they were not available in the form desired, for one reason, and because changing fire control practices and procedures make such data of less value, for another. The data gathered are shown in summarized form (table 1). The statistics on regular guard employment were furnished by the office of fire control in November 1937, while the remaining data were gathered by Leigh Wetmore, assisting the writer, from the Forms 924W and 930, in November and December 1937.

"Regular" short-term employees only are listed in table 1. Emergency employees are eliminated on the theory that they do not influence appreciably the foundation of trained men upon which fire protection depends. To be effective, guards must be trained experienced men. Emergency employees are of necessity largely untrained and inexperienced. For still another reason, emergency guards were eliminated. The determination of the amount and distribution of the regular allotted protection funds is considered by the Forest Service a pressing and important

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[1/] Show, S. B. and E. I. Kotok. The role of fire in the California pine forests. U.S.D.A. Bull. 1294. December, 1924.

__________ Cover type and fire control in the national forests of northern California. U.S.D.A. Bull. 1495. July, 1929.

__________ The determination of hour control for adequate fire protection in the major cover types of the California pine region. U.S.D.A. Tech. Bull. 209. August, 1930.

__________ Forest fires in California, 1911-1920. U.S.D.A. Circ. 243. February, 1923.

Table 1.- Number of forest guards on regular duty, acres burned and suppression costs, 12 northern California national forests, 1921-1937, inclusive.

Year	No. guards "regular"	Acres burned "inside"	Suppression costs, regular and E.C.W. "inside"
1921	339	38,885	50,851
1922	341	113,582	104,135
1923	305	44,462	68,357
1924	388	368,407 ✓	638,603
1925	341	25,364	70,049
1926	352	258,894 ✓	481,541
1927	394	42,289	152,886
1928	390	164,316 ✓	411,798
1929	457	130,191 ✓	348,017
1930	496	31,016	198,693
1931	508	128,926 ✓	488,646
1932	507	67,302 ✓	254,476
1933	667	20,720	95,122
1934	434	65,496 ✓	358,261
1935	1/ 593	11,557	202,116
1936	1/ 698	68,345 ✓	293,631
1937	1/ 623	10,553	238,949

11 80

235

1/ Adjusted to include "allotted" emergency positions.

problem[2] and it was expected that this analysis would provide some approach to a solution. Emergency guards are not paid from such funds.

In certain cases, in recent years, "regular" guards have been paid from "emergency" funds. To compensate for this certain adjustments were made in the number of regular guards listed in statistical summaries for years 1935, 1936, and 1937. The acreage burned figures are "total inside"; that is, the data apply to all fires within the established national forest boundaries whether on private or public land. Fires outside forest boundaries are eliminated. The above statements apply equally to suppression costs. It is unnecessary in this preliminary report to define fully the terms used in table 1, all clearly understandable to forest officers.

The problem of expending funds for preparedness may be stated as follows: What is the size of the "regular" force which can most efficiently be employed in the protection of a national forest unit? Lacking long range weather forecasts, this question must be asked for an average year. By and large, the bulwark of the protection force consists in the organized trained guards who function year after year, "good" season and "bad". The problem then is the determination of the size of force which must be regularly maintained from year to year to obtain most efficient protection.

Fortunately for this analysis, the data on guard hire ranges from 303 to 698, permitting within the 17 year range a definition of average results for this range of organization strength. It is obvious that generalization for any degree of organization strength for any one year is impossible because of the wide fluctuations usual in forest fire behavior conditions. *It is also obvious that with increased organization, reduction in acreage burned must result on the average over any series of years representing a fair sample of fire behavior conditions.* This is a fundamental consideration in the analysis following. The records of the individual years are then of little moment in this analysis — broad averages are desired.

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[2] Report of the Washington Fire Planning Conference, November, 1936. Fire Control Notes, March, 1937.

The first step in the analysis consisted in classifying the years according to number of men employed.[3] After trying several methods, a broad grouping consisting of four classes was adopted: 300-400, 400-500, 500-600, and 600-700 men. Further subdivision would have resulted in failure to obtain sufficient spread of fire behavior conditions within classes.

Having decided on the method of grouping, table 2 was prepared. The results of the averaging in table 2 are summarized in table 3.

For the case of suppression costs in year-group 1, tables 2 and 3, an explanation is necessary. Suppression costs are governed by both need and existing policy. A study of the statistics shows for the years following the disastrous 1924 season an obvious and clear-cut policy change leading to more liberal expenditures for fire suppression. For that reason the average suppression costs used for the eight years in group 1 are those of the five years from 1924 to 1928, excluding 1921, 1922, and 1923.

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[3] The technique of study of acreage burned as influenced by strength of force was first used by Show and Kotok in "Forest fires in California, 1911-1920."

Table 2.- Number of guards, acres burned, and suppression costs for groups of years, 12 northern California national forests, 1921-1937. Data grouped on intensity of guard employment.

Year	No. guards	Acres	Suppression costs
Group 1 - 300-400 Guards			
1921	339	38,885	$ 50,851
✓ 1922	341	113,582	104,135
1923	303	44,462	68,357
✓ 1924	388	368,407	638,603
1925	341	25,364	70,049
✓ 1926	352	258,894	481,541
1927	394	42,289	152,886
✓ 1928	390	164,316	411,798
Total	2,848	1,056,199	1,978,220
Average	356	132,024	247,277 [1] 350,975
Group 2 - 400-500 Guards			
✓ 1929	457	130,191	348,017
1930	496	31,016	198,693
✓ 1934	434	65,496	358,261
Total	1,387	226,703	904,971
Average	462	75,567	301,657
Group 3 - 500-600 Guards			
✓ 1931	508	128,926	488,646
✓ 1932	507	67,302	254,476
1935	593	11,557	202,116
Total	1,608	207,785	945,238
Average	536	69,262	315,079
Group 4 - 600-700 Guards			
1933	667	20,720	95,122
✓ 1936	698	68,343	293,631
1937	623	10,553	238,949
Total	1,988	99,616	627,702
Average	662	33,205	209,234

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[1] 1924-1928 inclusive.

Table 3.- Average number of guards, acres burned, and suppression costs, 12 northern California national forests, 1921-1937.

Area protected - 15,000,000 acres

Year group (1)	Guards employed (2)	Cases (3)	Average No. guards (4)	Average acres burned (5)	Average suppression costs (6)
					Dollars
1	300-400	8	356	132,024	1/ 350,975
2	400-500	3	462	75,567	301,657
3	500-600	3	536	69,262	315,079
4	600-700	3	662	33,205	209,234

1/ 1924-1928 inclusive, only.

The following analysis is based on the data of table 3.

Analysis

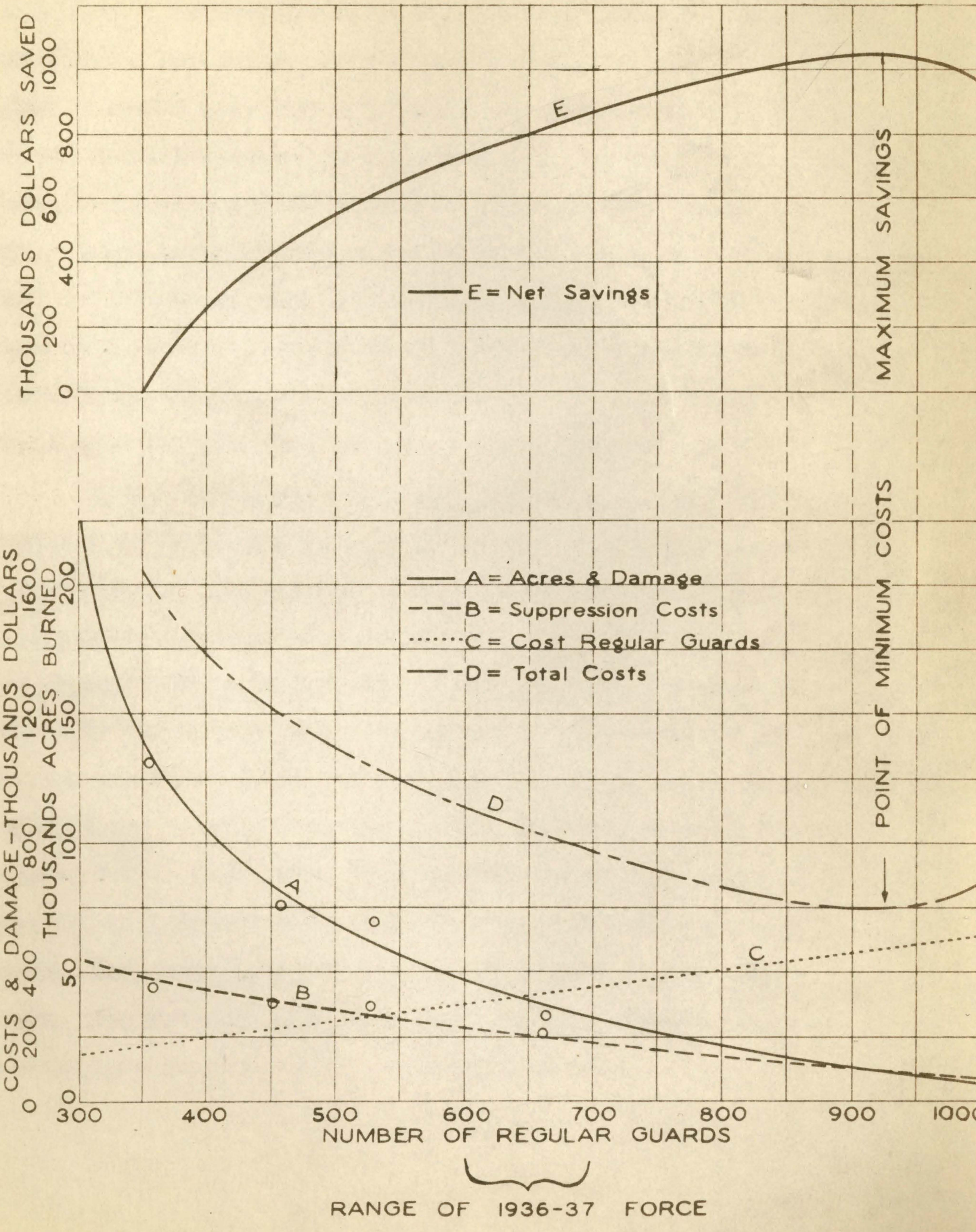
The data in column 5, table 3, acreage burned, were first plotted over average number of men, column 4, giving curve "A", figure 1. As found in preliminary analyses (fig. 2, 3) this curve follows a typical diminishing returns form, an obvious conclusion to a student of this subject. It is interesting to note how well these data fit a smooth curve (A, fig. 1). The definition of the curve to fit these points is of little importance to this preliminary study; it was simply fitted, freehand. This curve defines in a general way the experience which "experimenting" with various strengths of organization has produced in acreage burned in this region. This curve is freely extrapolated, regarding which, more later.

The next step consisted in placing an average value on acres burned. It is apparent that, for this type of analysis, an average value of damage for the region is desired. Over the period 1932-1936, 233,418 acres were burned over at an average estimated damage of $8.19 per acre. Damage figures are notoriously inadequate and unreliable. A rough figure of $8.00 was therefore adopted and curve "A" converted into a damage curve through the simple expedient of multiplying the area scale by $8.00.

Curve "B" was next prepared from statistics on suppression costs in column 6, table 3. Curve "B" is of similar, but of less pronounced form than curve "A". Policy controls "B" to a greater extent than "A" and little explanation of the failure of "B" to fall rapidly with increase of force and falling fire size is required for those who are familiar with the Forest Service policy in fire suppression of late years.

Figure 1

ANALYSIS OF MINIMUM COST
IN
FOREST FIRE PROTECTION
12 NORTHERN CALIFORNIA NATIONAL FORESTS
1921-1937 DATA



Curve "C", figure 1, costs of guard employment was plotted next. To simplify the procedure, a cost of $500 per guard year, for an average employment of 4.2 months, was derived from statistics on current guard employment. This figure should provide for all current expenses attributable to guard hire as tools, equipment, transportation and the like, as we are interested here not in the bare wages of the guard but in the proportional share of total costs which can be ascribed to the employment of a single guard. Overhead costs, on the other hand, can logically be left out of this analysis. Accordingly, the total costs of fire protection are considered to be the sum of (1) damage, (2) suppression, (3) guard expense (preparedness). By adding the three curved values for any guard class the composite total costs curve "D" is constructed.

Curve "D", falling at first with increase of force, must eventually arrive at point of inflection, for with costs of guard hire increasing and suppression costs and damage decreasing, the point must eventually be reached where the costs of adding additional men will just balance the decrease obtained in the combined suppression and damage costs. Thereafter the costs of additional men must be at a greater expense than the decrease in S + D and cannot be justified. To determine this point, extrapolation is used. Such extrapolation is clearly justified in this type of study. It is obvious that curve "A" can neither rise nor reach zero but is asymptotic to the zero line. The same applies to curve "B". Accordingly, we can extrapolate as indicated. With the extrapolated curve, the point of inflection of curve "D" is determined at 925 men, and men added thereafter result in loss in efficiency.

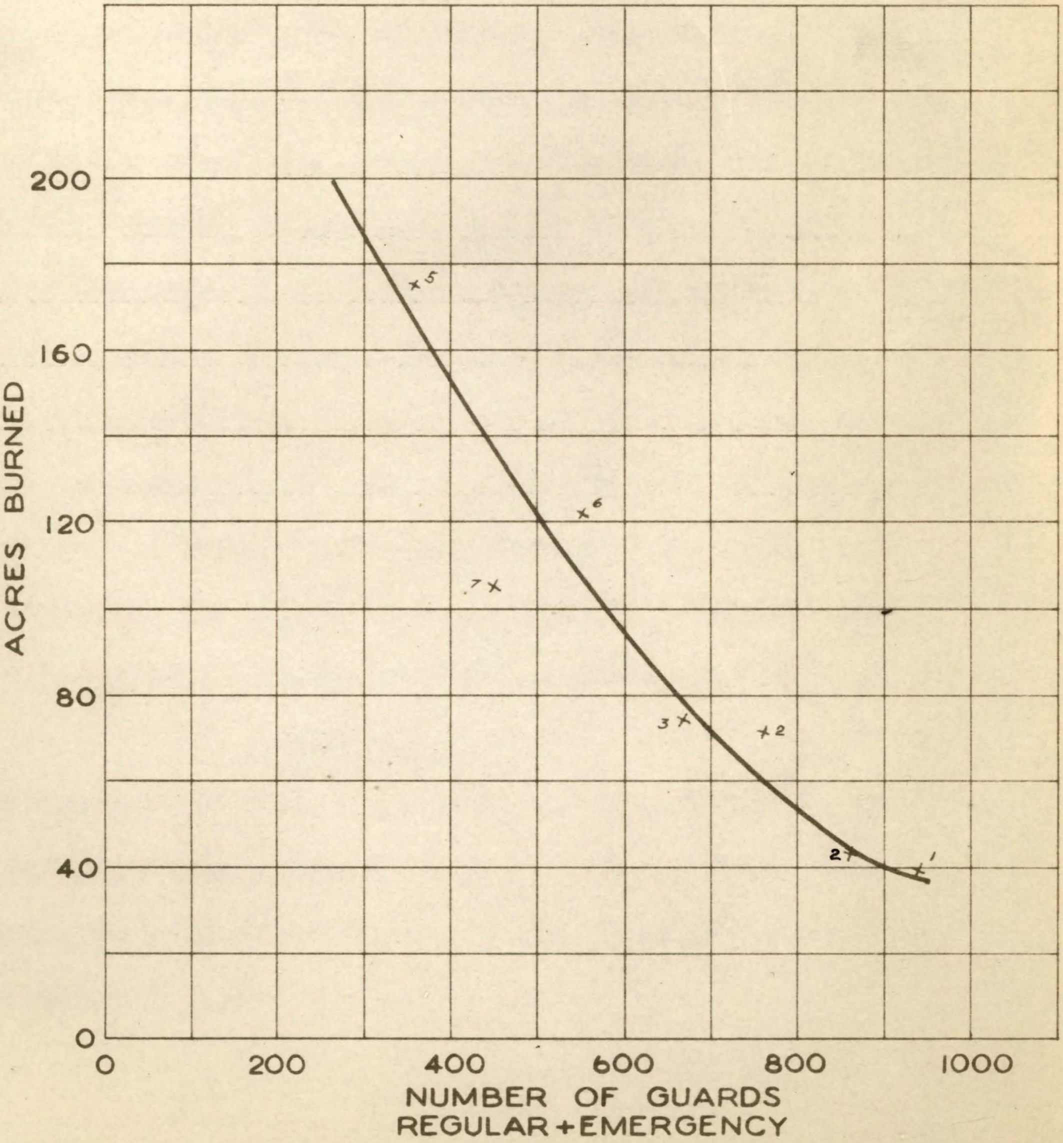
Figure 2

PRELIMINARY CURVE

INFLUENCE OF TOTAL NO. OF MEN EMPLOYED IN REGION – REGULAR AND EMERGENCY – ON ACRES BURNED.

12 NORTHERN CALIFORNIA FORESTS

1911 – 1937



Curve "E" is next derived from curve "D" to show the net saving accompanying the cost reduction shown in "D". This curve is derived by conceiving of an existing organization with 350 men and from this base computing the changes in total cost accompanying the addition of man power. From curve "E" the savings or losses of adding any man power strength may be directly computed. It shows, for instance, an average saving to government of the United States of $225,000 with increase of force from the present number of 650 to 925 in this region.

In addition to indicating the point of maximum advantage in organization, this analysis also indicates the allowable burned acreage. The extrapolated curves indicate that burned acreage might be held efficiently under 10,000 acres, less than 1/15 of 1 percent of the 15 million acres protected. This may be contrasted to the accepted figure of 26,000 acres at the present time. These figures are, as in other discussions, to be subjected to correction in the refined analysis.

Specific recommendation of this kind is, however, not the intention of this study. Before increasing forces to any number as indicated, this analysis, made for illustrative purposes, should be carefully reconsidered and improved. The point, however, that size of forces has not yet reached most efficient size seems firmly established.

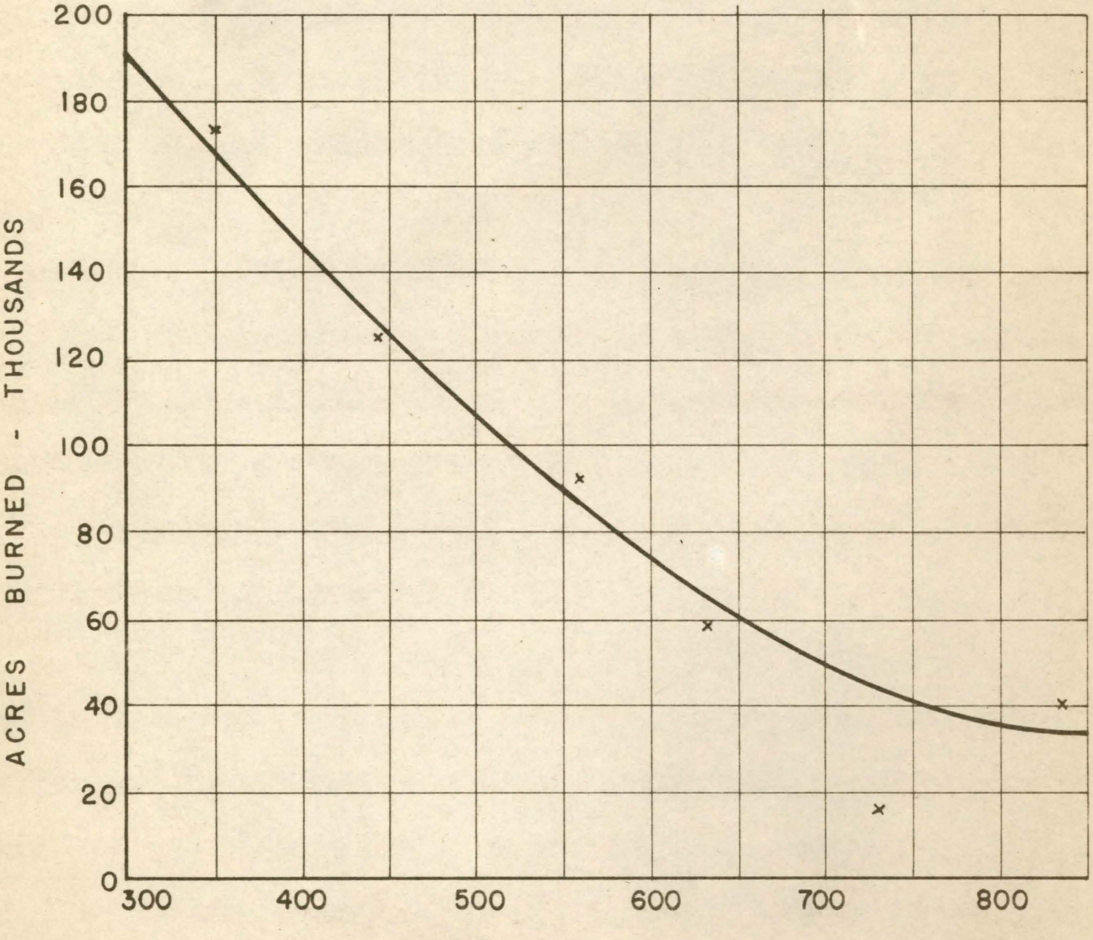
Applications

It is apparent that with reliable damage data this method provides an improved method of solving fire control economic problems. Comparison analyses between units on the basis of correlated damage must in the end produce equitable fund distribution.

FIG. 3

PRELIMINARY CURVE

ANALYSIS OF TOTAL NUMBER OF "REGULAR" GUARDS EMPLOYED IN REGION AND INFLUENCES ON AVERAGE AREA BURNED, 12 NORTHERN CALIFORNIA NATIONAL FORESTS, 1911 - '37 INCLUSIVE. DATA FOR 1911-'20 INCLUDES SOME "EMERGENCY" GUARDS.



The importance of accurate damage data for this type of analysis is obvious. Suppose the public damage is, in fact, $16,00 per acre in northern California. If the damage scale is changed to correspond to this value, the "C" curve drops and the point of inflection travels far to the right. Comparisons of regions on the basis of this type of analysis would be obviously unfair without close correlation of damage figures, something which has not been attempted.

Application of this analysis is broad. It results, it appears, in the first clear definition of the economic theory of fire protection. Such theory has failed as a general guide because no means of determining the manner in which increasing expenditures affect the reduction of damage and suppression costs was available. This method fills this need.

Other apparent advantages of this method of analysis are mentioned here.

Given analyses of two or more units, comparison of efficiency gained in increasing expenditures on each is readily made. Money can be distributed scientifically to provide the greatest net return. Comparisons can be readily made between units of different size.

Analyses of this type provide a basis for comparisons of efficiency of expenditures from one unit to the next.

In general, it would appear that the analysis developed here is adapted to the solution of most of the real problems of scientific management of fire control expenditures. It provides, further, incontrovertible evidence for positive forest protection policies.

The analysis presents, more clearly than hitherto, the true unvarying relationships existing between P, S, D, a classic forest protection problem.

It is a simple direct method which can be completed in a few hours for any unit from a forest to the nation from data readily available.

[redacted]

Several criticisms of the analysis may occur to the student of fire protection. That the fall in "A" is due in part to improved facilities as well as to increased man power is an obvious conclusion. Such intercorrelation between increased man power and facilities unquestionably exists and is granted. The man power figures are used not only in an absolute sense but also as an index of general improvement in fire control. Such intercorrelation should not in any case destroy the validity of the conclusion if the other data are reliable. With present status in improvements, increased man power must decrease acreage, in general, as shown.

It would be interesting and valuable to remove the influence of improved facilities from curve "A" to determine the net value of improved man power. One approach to this involves use of previous decade statistics which are unfortunately at present confused by the lack of isolation of "regular" from "emergency" positions. An attempt of this kind is planned when the data are analyzed carefully for policy argument. Other methods exist through consideration of increase in size and cost of physical plant and facilities; viz. roads, telephone lines, lookout structures.

Some may consider that the plotting of preparedness costs in dollars on the horizontal axis would be desirable. This and other modifications of the method are possible. To the writer the use of strength of organization, with the distribution of total costs according to number of guards, provides a more concrete and definite analysis. The basis of forest protection is still the guard, lookout or fireman, and to him and his kind can be logically ascribed reduction in acres burned.

It is interesting to speculate on the influence of changes in practices and procedures on curves "A", "B", "C", and "D". Increase in efficiency of protection through road and trail construction should influence "A" and "B", shifting both curves downward with increased efficiency. This would result in the point of inflection of "D" moving to the left and in obtaining the greatest efficiency with smaller numbers of guards. If costs other than guard salaries and simple expenses are included in curve "C" the effect is to raise the whole curve a certain amount and to move the inflection point to the left. Other similar assumptions may be made and their influence tested on those curves.

The question could be raised as to the influence of CCC on costs. Apparently the net effect as far as national forests are concerned has been small. Increase in strength of attack has been accompanied also by increase in elapsed time and it appears that the net result may be little different than when single guards were more common. The large crews once used exclusively for fire suppression were undoubtedly uneconomic. Little of the time of suppression crews is, under present practice, chargeable to preparedness inasmuch as all are engaged full time in project work.

The curve fitting is rough; therefore definite conclusions should not be drawn on this preliminary analysis.

Conclusions

These hypotheses and analyses provide the basis for a restatement of the economic theory of fire protection, developed by Roy Headley. Preparedness costs govern both costs of suppression and costs of damage under the general law of diminishing returns: with increasing preparedness costs resulting in decreasing damage and suppression costs, a point must eventually be reached where the sum of all costs attains a minimum.

This point defines both maximum efficient preparedness expenditures and the resulting acceptable area burned.

I should like to express my appreciation of help and suggestions received from two of my co-workers, W. L. Fons and C. A. Abell.

Appendix

H. D. Bruce volunteered to analyze the data in table 3 independently and mathematically with the following results:

June 11, 1938

MEMORANDUM FOR J. R. CURRY

According to your California data:

The "Damage" curve is a simple hyperbola of formula

$$D = 3.053 \cdot 10^{11} M^{-2.134}$$

The "Suppression" curve is a simple hyperbola of formula

$$S = 7.354 \cdot 10^{7} M^{-0.9}$$

The "Protection" labor cost is a straight line of formula

$$P = 500 M$$

The total cost curve has the following complex formula,

$$(P+S+D) = 500 M + 7.354 \cdot 10^{7} M^{-0.9} + 3.053 \cdot 10^{11} M^{-2.134}$$

The total cost curve has its minimum where M satisfies this equation:

$$6.6186 \cdot 10^{7} M^{-1.9} + 6.5162 \cdot 10^{11} M^{-3.134} = 500$$

The M which satisfies the above equation is 913, beyond which the total cost begins to increase.

In the above, D = cost of damage in dollars,

S = suppression cost in dollars,

P = cost of guard labor in dollars,

M = number of men (guards).

BRUCE